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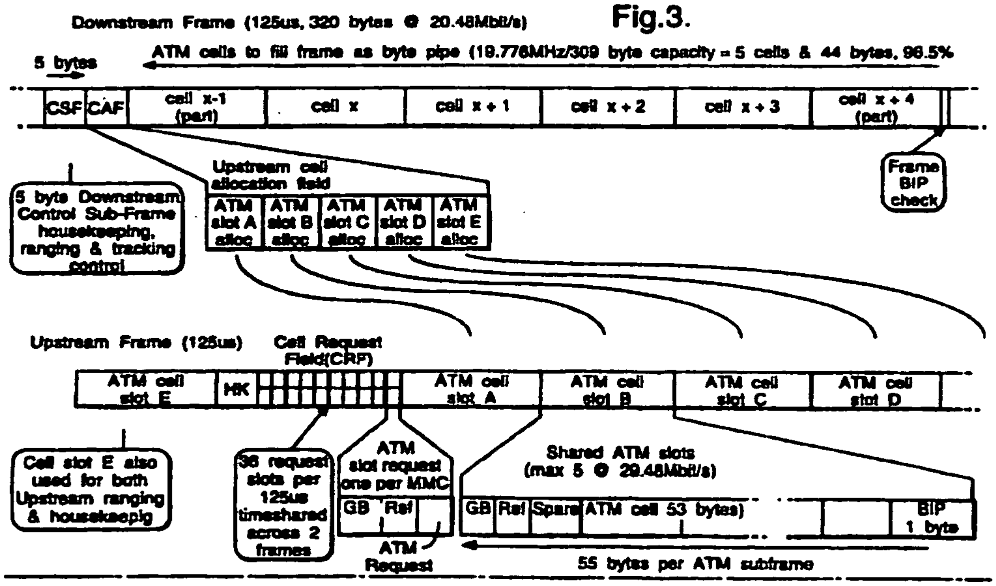
(54) **A bi-directional communications network**

(57) A bi-directional communications network (e.g. for video telephony or work-at-home data application) is disclosed, and in particular a TDM/TDMA protocol for the shared coax medium downstream/upstream resource. The protocol includes a high data rate upstream channel which transmits at the same data rate as the downstream channel. This protocol enables very high bandwidth efficiency in the upstream channel. This protocol provides a very efficient technique for resource sharing in the Access Network of HFC systems. A TDMA protocol operable in a communications network, is also disclosed, wherein each outstation has an ATM cell slot request mechanism and an ATM cell slot request slot in every frame and the basestation allocates cell slots to outstations on a per-frame basis. This provides dedicated-per-user, short cell-request time slots in the TDMA frame to allow cell allocation before the start of the next downstream cell allocation burst.

Fig.3.



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

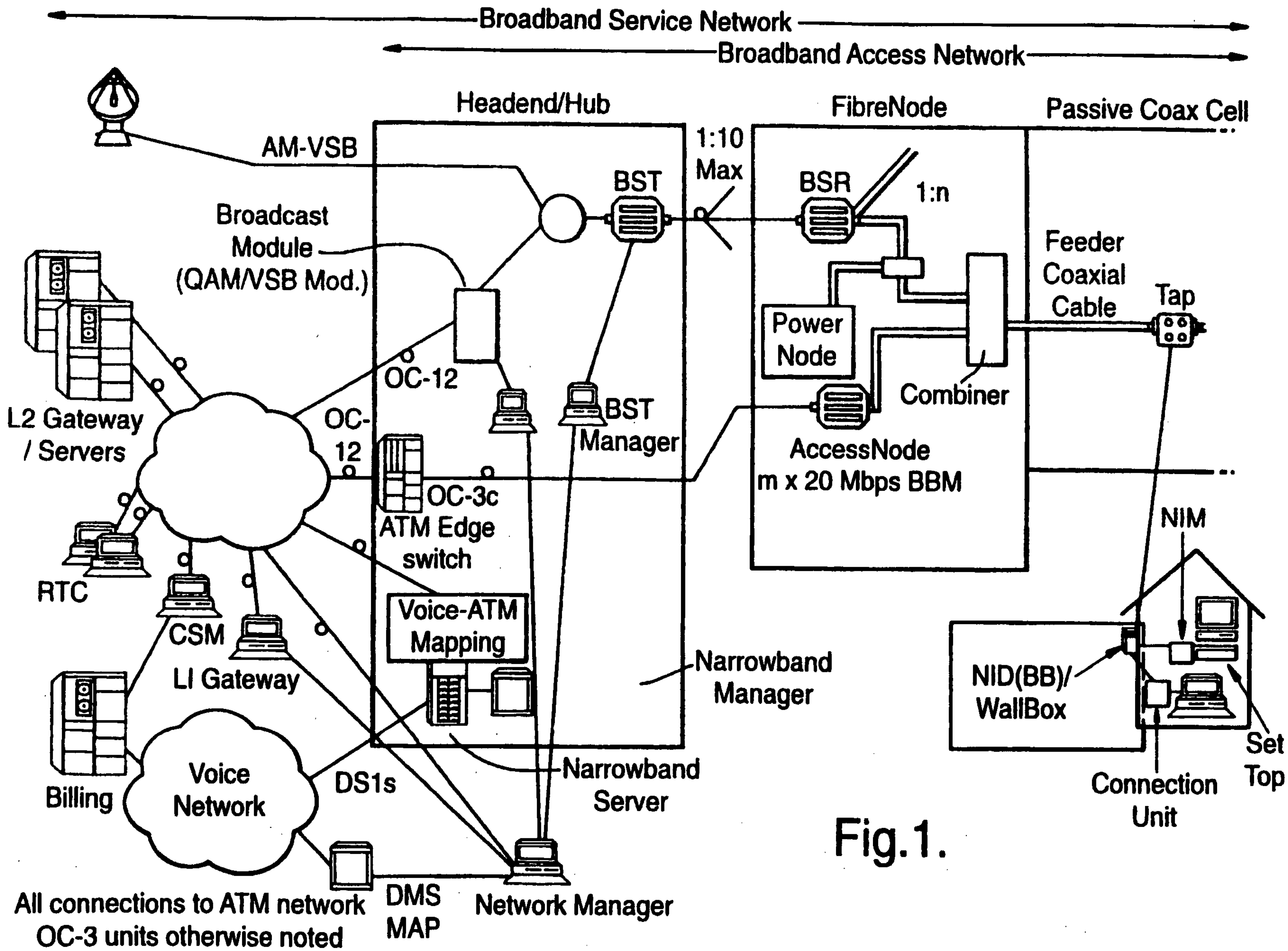

Broadband Service Network
Broadband Access Network
Headend/Hub
FibreNode
Passive Coax Cell
AM-VSB
1:10
Max
BST
BSR
1:n
Broadcast
Module
(QAM/VSB Mod.)
Feeder
Coaxial
Cable
Tap
Power
Node
OC-12
Combiner
L2 Gateway
/ Servers
OC-
12
BST
Manager
AccessNode
m x 20 Mbps BBM
OC-3c
ATM Edge
switch
NIM
RTC
Voice-ATM
Mapping
CSM
Narrowband
Manager
NID(BB)/
WallBox
LI Gateway
Billing
Voice
Network
DS1s
Narrowband
Server
Set
Top
Connection
Unit
All connections to ATM network
OC-3 units otherwise noted
DMS
MAP
Network Manager

Fig.1.

Fig.2.

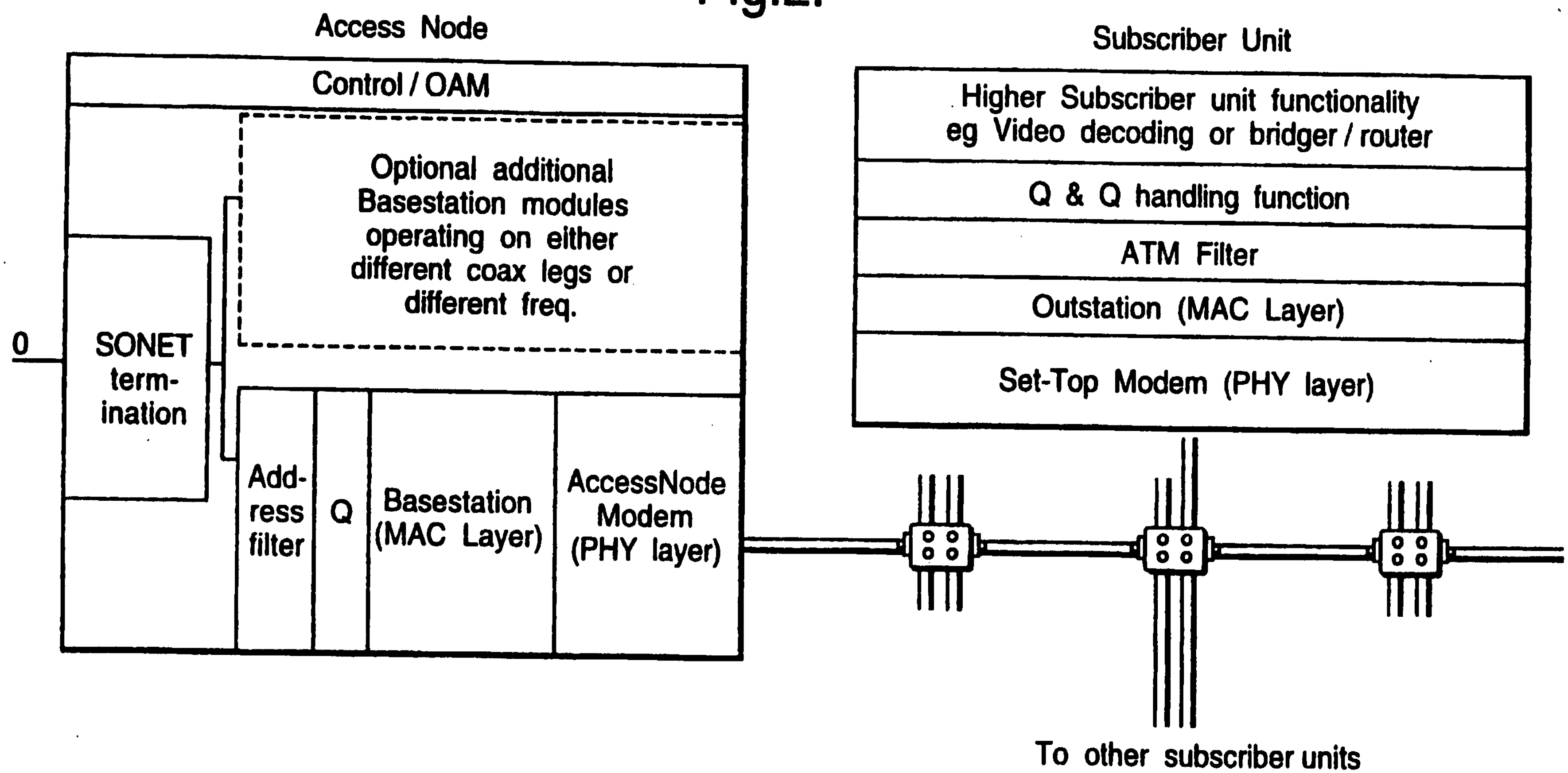

Access Node
Control / OAM
Optional additional Basestation modules operating on either different coax legs or different freq.
0
SONET term-ination
Add-ress filter
Q
Basestation (MAC Layer)
AccessNode Modem (PHY layer)
Subscriber Unit
Higher Subscriber unit functionality eg Video decoding or bridger / router
Q & Q handling function
ATM Filter
Outstation (MAC Layer)
Set-Top Modem (PHY layer)
To other subscriber units

Fig.3.

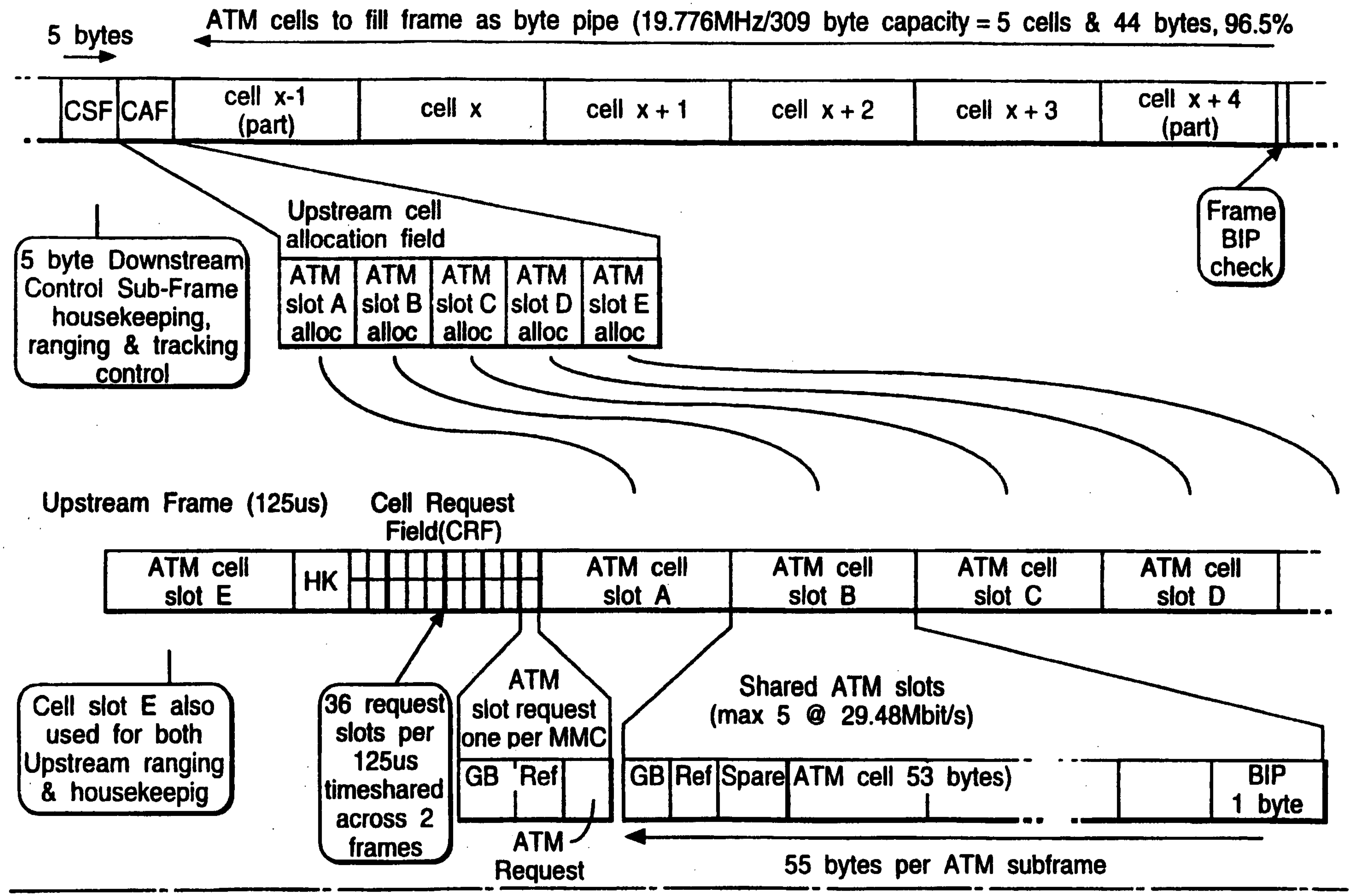

Downstream Frame (125us, 320 bytes @ 20.48Mbit/s)
5 bytes
ATM cells to fill frame as byte pipe (19.776MHz/309 byte capacity = 5 cells & 44 bytes, 96.5%
CSF
CAF
cell x-1 (part)
cell x
cell x + 1
cell x + 2
cell x + 3
cell x + 4 (part)
Frame BIP check
5 byte Downstream Control Sub-Frame housekeeping, ranging & tracking control
Upstream cell allocation field
ATM slot A alloc
ATM slot B alloc
ATM slot C alloc
ATM slot D alloc
ATM slot E alloc
Upstream Frame (125us)
Cell Request Field(CRF)
ATM cell slot E
HK
ATM cell slot A
ATM cell slot B
ATM cell slot C
ATM cell slot D
Cell slot E also used for both Upstream ranging & housekeepig
36 request slots per 125us timeshared across 2 frames
ATM slot request one per MMC
GB
Ref
ATM Request
Shared ATM slots (max 5 @ 29.48Mbit/s)
GB
Ref
Spare
ATM cell 53 bytes)
BIP 1 byte
55 bytes per ATM subframe

Fig.3(Cont).

<u>Downstream Byte Types:</u>
Control sub-frame (5 byte field)
Cell allocation field (7 bits + odd parity) 128 outstations max
Cell byte: as byte pipe
Frame BIP

<u>Upstream Byte Types:</u>
Control slot byte (1 byte guard, 53 byte cell, 1 byte BIP)
Cell request field (10 bits)
Housekeeping defined field within slot E (or whole ATM cell)

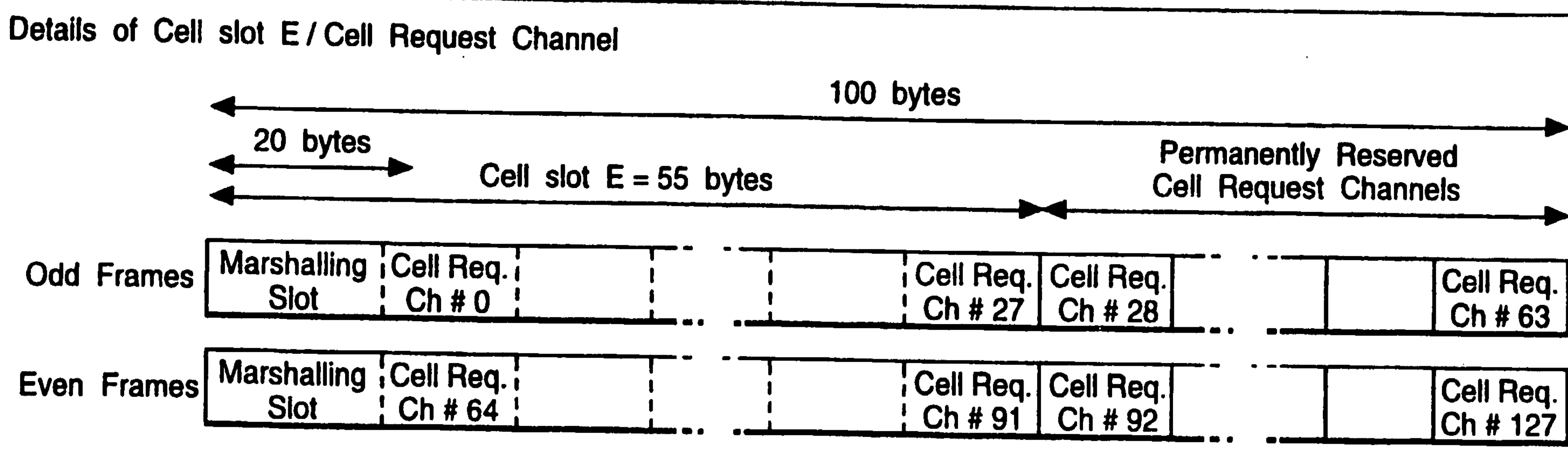


Fig.4.

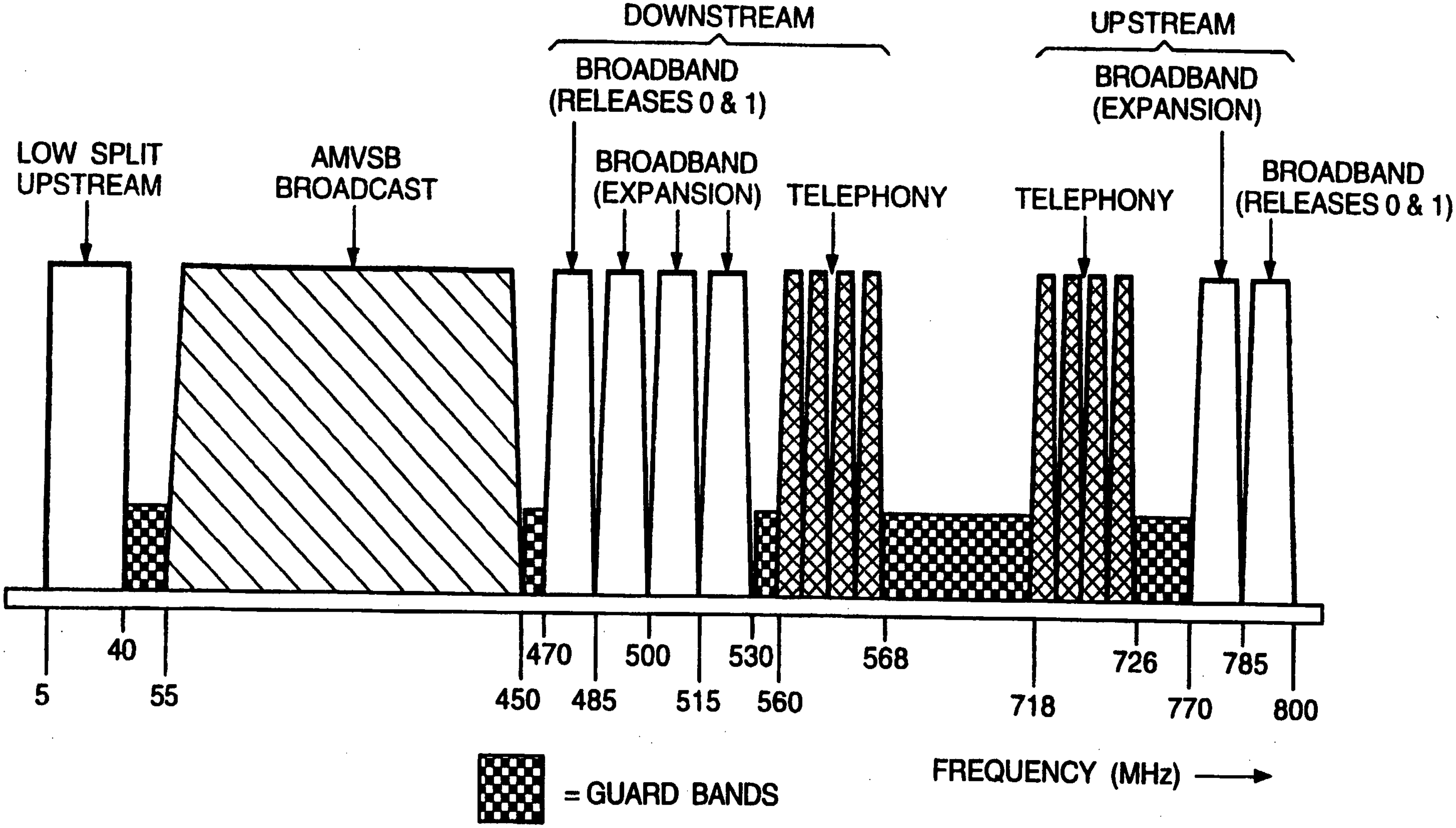

DOWNSTREAM
UPSTREAM
BROADBAND
(RELEASES 0 & 1)
LOW SPLIT
UPSTREAM
AMVSB
BROADCAST
BROADBAND
(EXPANSION)
TELEPHONY
TELEPHONY
BROADBAND
(EXPANSION)
BROADBAND
(RELEASES 0 & 1)
5
40
55
450
470
485
500
515
530
560
568
718
726
770
785
800
= GUARD BANDS
FREQUENCY (MHz)

Fig.5.

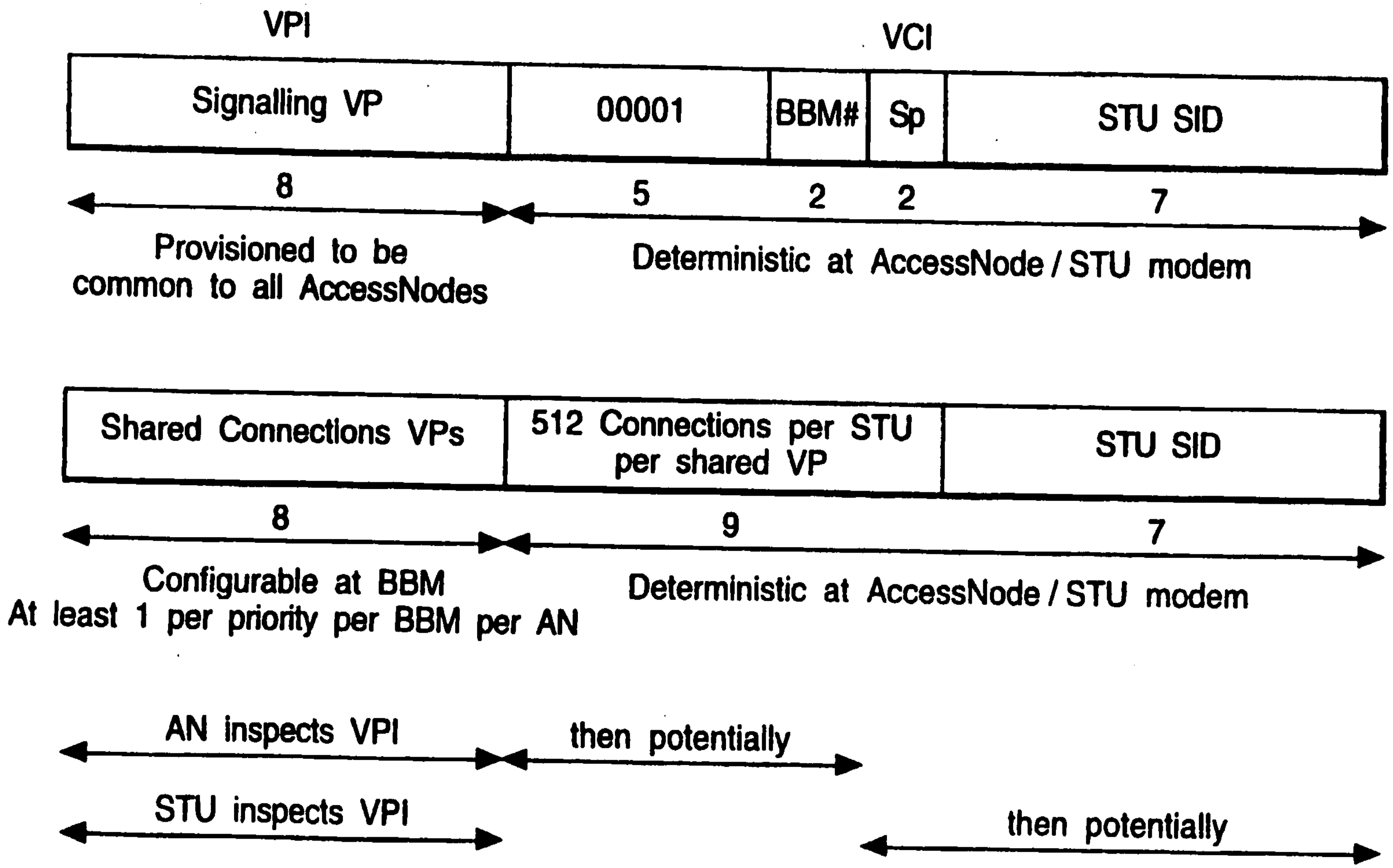
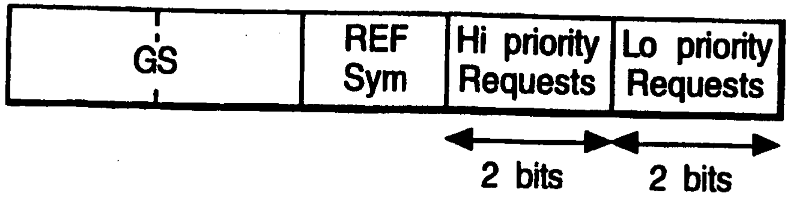

VPI
VCI
Signalling VP
00001
BBM#
Sp
STU SID
8
5
2
2
7
Provisioned to be common to all AccessNodes
Deterministic at AccessNode / STU modem
Shared Connections VPs
512 Connections per STU per shared VP
STU SID
8
9
7
Configurable at BBM
At least 1 per priority per BBM per AN
Deterministic at AccessNode / STU modem
AN inspects VPI
then potentially
STU inspects VPI
then potentially

Fig.6.



Hi priority Q Fill - this frame cell allocation <=0 Hi Pr. Req =00,
Hi priority Q Fill - this frame cell allocation =1 Hi Pr. Req =01,
Hi priority Q Fill - this frame cell allocation =2 or 3 Hi Pr. Req =10,
Hi priority Q Fill - this frame cell allocation =>4 Hi Pr. Req =11,

Lo priority Q Fill - ABS (this frame cell location - Hi Priority Q fill) <=0 Lo Pr. Req =00,
Lo priority Q Fill - ABS (this frame cell location - Hi Priority Q fill) =1 or 2 Lo Pr. Req =01,
Lo priority Q Fill - ABS (this frame cell location - Hi Priority Q fill) =3 to 8 Lo Pr. Req =10,
Lo priority Q Fill - ABS (this frame cell location - Hi Priority Q fill) =>9 Lo Pr. Req =11,

ABS in this case means all negative values = 0

Fig.7.

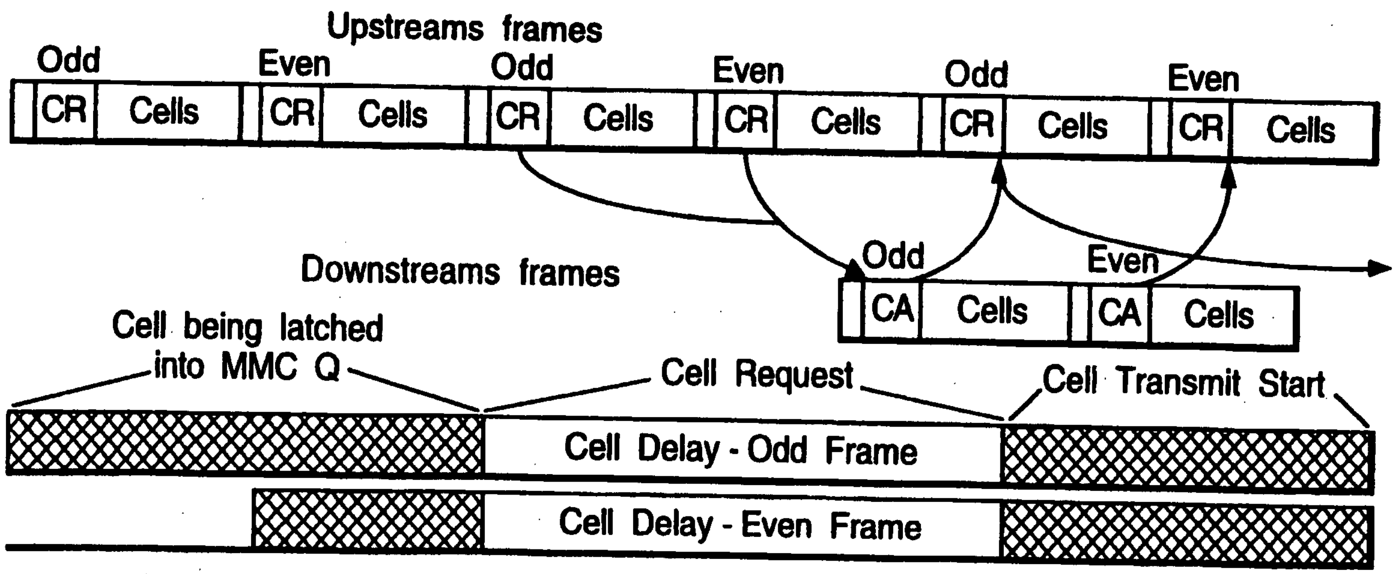
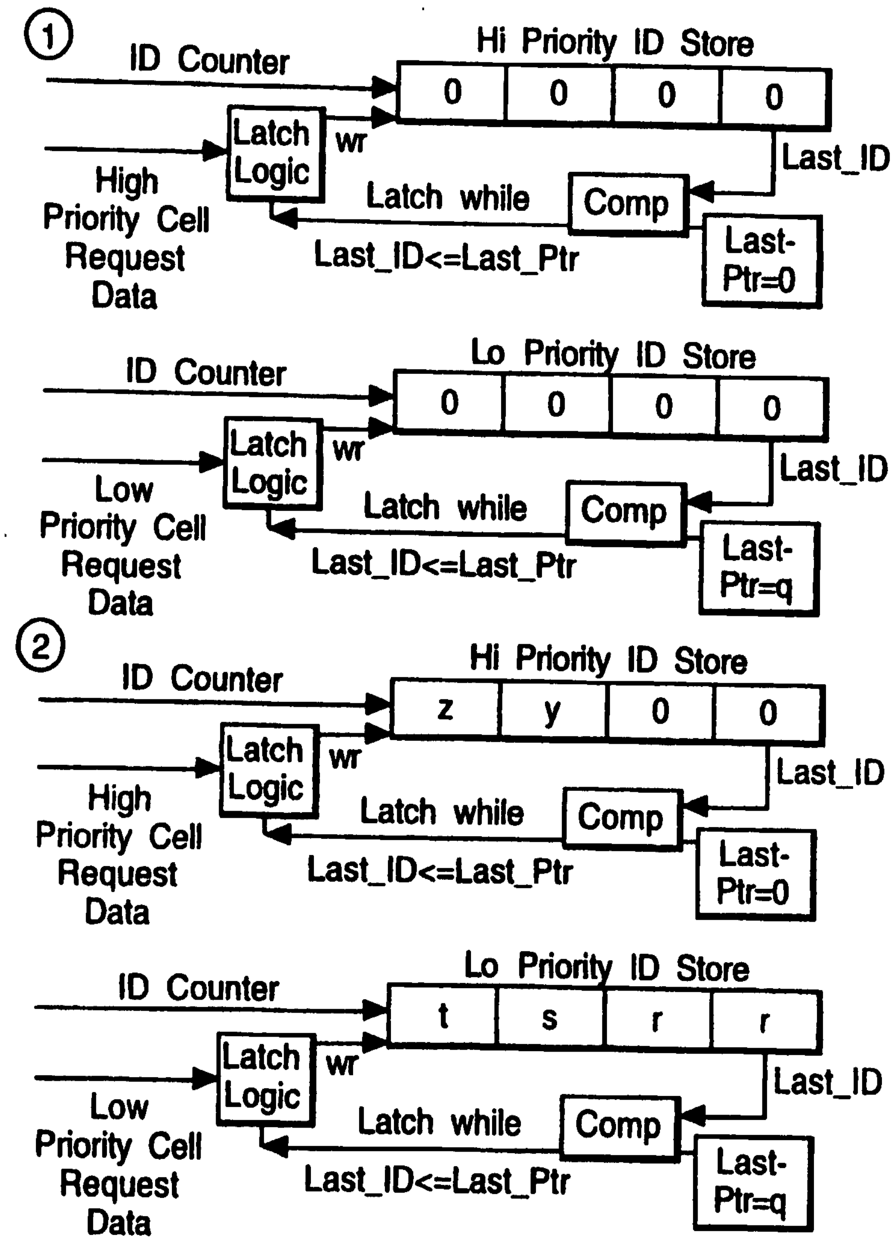


Fig.8.



<u>Initial status</u>

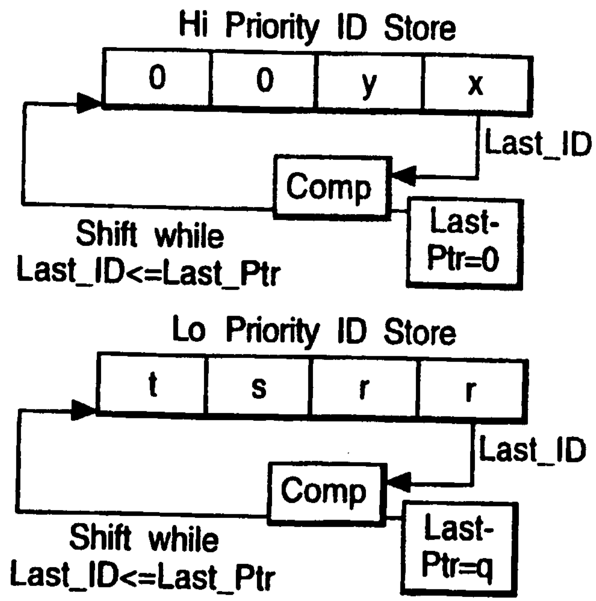
At start of cell Request Stream, Last_Ptr(Hi)=0
ie all Hi Priority cell requests allocated last frame
Last_Ptr(Lo)=q
ie Not all Lo Priority Cell requests allocated last frame
and last one allocated was to MMC#q
High priority stream x=1, y=1 all else 0
Low priority stream p=1, r=2, s=1, t=1, u=1

<u>Cell Request Capture Phase</u>

At end of cell Request Stream,
all High priority cell requests captured as
less than Max capacity (here shown as 4)
low priority request from MMC#p latched thru
and lost as P<q,
low priority request from MMC#u not latched
as store full

Fig.8 (Cont i).

3



Cell Request Process Phase

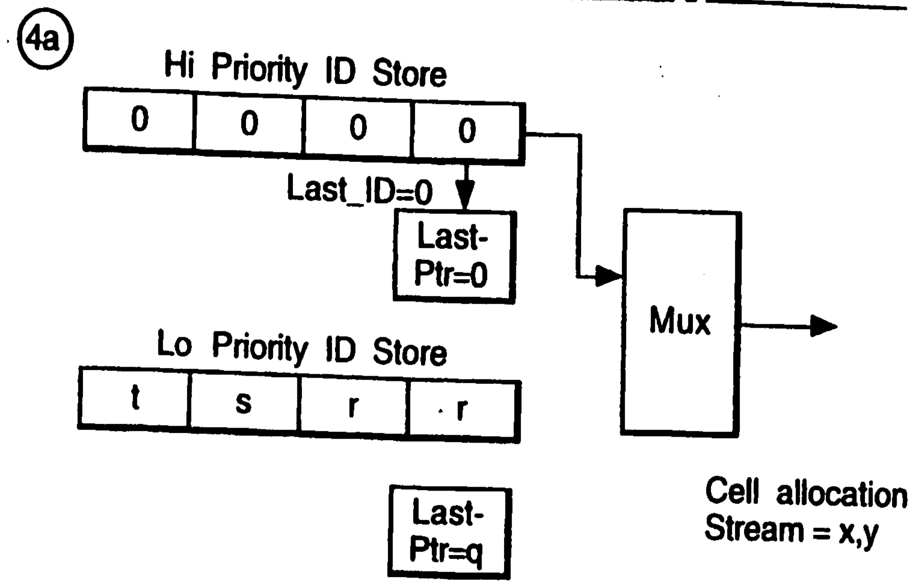
Shift ID store unit Last_ID>Last_Ptr
(this is the case in this scenario for Lo priority where nul action)
or
(next frame capacity of coax is available AND
Last_Ptr ne 0)

This is the case in this scenario for Hi priority cell requests

next frame capacity is smaller value of
a) configured capacity of PCN (3,4 or 5)
b) (PON capacity - Q fill) (0 to 10?)

For these examples assume next frame capacity =3 cells

Fig.8 (Cont ii).

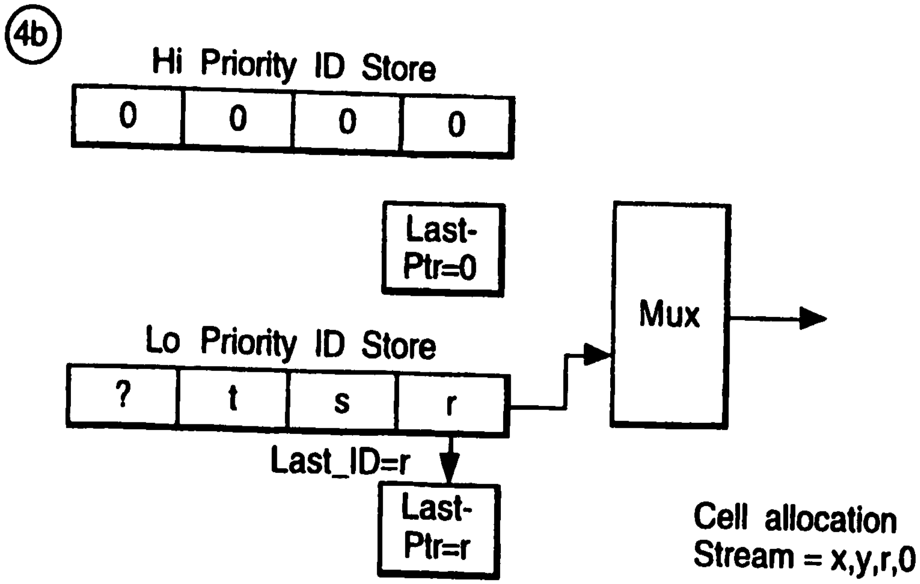


<u>Cell allocation Phase</u>

Allocate from Hi priority ID store until either
a) no more Hi priority requests (this scenario) or
b) all next frame capacity has been allocated

if more capacity in next frame then cell requests then set Last_Ptr (Hi) to 0 (as here) else latch last allocated Hi Pr.ID into last_Ptr(hi)

Once Hi Priority ID store is empty and there is still capacity to be allocated, reprocess to priority store until Last_ID>Last_Ptr
or
remainder of next frame capacity of coax is available
THEN
shift IDs out of low priority ID store



if still more capacity in next frame than cell requests then set Last_Ptr (Lo) to 0 else latch last allocated Lo Pr. ID into last_Ptr(Lo)

Once capacity has been allocated, set all remaining allocation opportunities to 0

Once allocation complete zero ID stores for next frame

Glossary

AM-VSB	Amplitude Modulation- Vestigial side band
ATM	Asynchronous Timing Mode
BIP	Bit interleaved parity
BSR	Broadband Services Receiver (A broadband analogue optical receiver)
BST	Broadband Services Transmitter (A broadband analogue optical transmitter)
CAF	Cell Allocation Field
CATV	Community Antenna TeleVision (another term for cable delivered TV)
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
CO	Central Office
CSF	Common Sub-Frame
DQPSK	Differential Quaternary Phase Shift Keying
EO	Electrical Optical (conversion point)
FIFO	First-In First-Out
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
HEC	Header Error Correction
HFC	Hybrid Fiber Coax
ID	Identity
LAN	Local Area Network
MAC	Medium Access Control
MMI	Multi-Media Interactive (a broadband service offered to end-customers)
MPEG	Motion Picture Expert Group (a protocol for compressing video signals)
NID	Network Interface Device (A point in the network used for protection and demarcation)
NTC	Network Termination Control
OAM	Operations, Administration & Maintenance
PPV	Pay Per View
QAM	Quadrature Amplitude Modulation
QPSK	Quaternary Phase Shift Keying

RF	Radio Frequency
SID	Short ID
SONET	Synchronous Optical NETwork
STU	Set Top Unit
STS	Synchronous Timing Signal
TDM	Time Divion Multiplex
TDMA	Time Division Multiple Access
VBR	Variable Bit Rate
VC	Virtual Channel
VCI	Virtual Channel Identifier
VOD	Video On Demand
VP	Virtual Path
VPI	Virtual Path Identifier

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GIBBS 2, 3, 4 GB

A BI-DIRECTIONAL COMMUNICATIONS NETWORK

Field of the Invention

The present invention relates to a bi-directional communications network, and in particular relates to a cable communication system.

Background of the Invention

Traditional hybrid fibre-coax (HFC) architectures have been deployed with a downstream one way only broadcast service requirement, with no, or limited cable return path. Recently, as network providers and equipment manufacturers have started to explore the options for high capacity two-way services, the limitations of the original system choices have become apparent. A symmetrical bandwidth or a more symmetric bandwidth than at present is described. This will allow the development of high capacity 2-way services. Examples of such two way (more symmetric) services include video telephony and work-at-home data applications (as opposed to INTERNET browsing). Such 2-way or highly interactive services enable more economic growth of HFC networks in the future.

Data services used for downloading from central servers are asymmetric, but can be highly symmetric if they are used for work-at-home or remote "grass roots" publishing applications. In the latter case, each subscriber's "download" becomes the publisher's "upload". In order that one may subscribe to the Ethernet requires instantaneous 2-way bandwidths of up to 10 Mb/s, although 2 Mb/s upstream is likely to be sufficient for browsing. Preferably latency must be keep low, nominally less than 10 msec, particularly in a LAN environment.

Video conference bandwidths are symmetric although lower than those for data or entertainment - 384 Kb/s to 2 Mb/s. Holding times however could be several hours, which impacts the upstream capacity engineering of the access plant. To the extent that any of the data or video services are used for business applications, they would have to have a reliability requirement approaching that of telephony today. The reliability requirement also affects the engineering choices in the access plant, requiring small failure group size.

The upstream capacity is limited in hybrid fiber coaxial designs by the characteristics of the spectrum - the low end of the band in the 5 to 40 MHz region - to which upstream traffic has been assigned in cable industry practice. This spectrum has problems with a high noise floor due in part to ingress by subscriber's cable plant noise. The presence of noise limits both the absolute amount of bandwidth available for upstream use, and the maximum bandwidth of any single channel. In practice, the limit is about 5 to 8 channels of 2 MHz each, which results in about 10 to 16 Mb/s of total bandwidth in a TDMA system, factoring in modulation index and overheads. Furthermore, the modems need to be dynamically agile to be able to seek quiet areas of the spectrum as interference conditions change.

Use of the high end of the band (> 350 to 500 MHz) allows larger contiguous blocks of bandwidth and such bandwidth is subject to less noise sources. Higher attenuation losses are incurred due to the higher frequencies, but the reduced transmission path distances caused by placing the electro-optic conversion plant deep in the access network (i.e. closer to the subscriber) avoid the need for expensive additional bi-directional amplifiers.

A design that uses remote digital electronics to provide high upstream bandwidth to a group of around 240 subscribers on a coax leg provides higher reliability than existing analogue systems and constrains the failure group size to limits normally acceptable in the industry for telephony. Average upstream bandwidth per subscriber can be increased by further reducing the number of customers served on a

single coax leg, thereby reducing both noise ingress and the total demand for upstream bandwidth on that coax leg.

To accommodate a diverse service mix such as LAN, video conferencing, games and VOD, it would be desirable to have a transport layer which utilizes the ATM format to carry all information and signalling between the central office and the home. The ATM format has been extended to the periphery of the broadband network since it provides a simple, consistent method for handling virtual circuits of different bandwidths and of different delay and burst characteristics over a single network. Further, ATM supports evolution of the MPEG bit rate as silicon speeds increase and more sophisticated decoding techniques are developed.

A cable system should preferably have the following key characteristics: the ability to co-exist with existing broadcast cable architectures; high capacity in both the downstream and upstream direction for switched digital services, acheived by inserting and extracting bandwidth deep in the outside plant, closer to the subscriber than traditional headend broadcast architectures; the ability to support a wide range of video and data services without preconfiguration; support of low latency upstream requirements; flexible deployment options to allow for increasing penetration of high upstream bandwidth interactive services.

The architecture of multiple users sharing bi-directional bandwidth on a shared access medium leads to a number of implementation possibilities: firstly it is assumed that there is little community-of-interest between adjacent subscribers and any such traffic can be "hairpinned" via the core network. This allows simplification of the system to a point to multi-point (rather than a multi-point to multi-point). In the downstream direction (point to multi-point) traffic is "broadcast" and is received at all subscribers. A single FDM channel could be allocated (either statically or dynamically) to each subscriber within the coax leg to limit access, but this requires a large number of different frequency modems at the access node and either frequency adaptable modems or a large number of variant outstation types. It also complicates configuration of the

network and obviously limits the peak downstream bandwidth to any one subscriber. Thus a TDM method is preferable to allow bursty downstream bandwidth. This could either be a single very broad TDM channel or a small numbers of less broad TDM channels, each one allocated statically to a block of subscribers - which implementation is adopted makes no difference to this invention.

Upstream (multi-point to point) various possibilities can be considered, amongst them: FDMA, TDMA and CDMA. FDMA is ruled out for the same reason as FDM . CDMA allows all users access to the whole bandwidth, but the cost/complexity of CDMA where the subscribers/outstations are capable of continually varying data rates outweighs the benefits. A TDMA system based on ATM presents a potential solution where each TDMA timeslot holds an ATM cell and use of such timeslots could be individually allocated in a dynamic fashion. The rest of this invention describes a system where TDM is used downstream and TDMA is used upstream.

It is an object of this invention to provide an improved method of operating a TDM/TDMA system for a dynamically varying bandwidth usage. Moreover, it is an object of this invention is to provide a TDMA protocol operable in a cable network wherein the bandwidth used for control purposes does not appreciably impact that used for user traffic.

Summary of the Invention

In accordance with an aspect of the present invention, there is provided a TDM/TDMA protocol operable in a communications network wherein each outstation has an ATM cell slot request mechanism with an ATM cell slot request slot in every frame and the basestation allocates ATM cell slots to outstations on a per-frame basis and this information is conveyed back to the outstations in the downstream signal, before the start of the next upstream burst.

In accordance with another aspect of the invention, there is provided a TDM/TDMA protocol operable in an ATM based communications

network wherein each outstation has an ATM cell slot request mechanism involving an assigned cell slot request slot in every frame (or at a known point every period comprising a number of frames) and the basestation allocates cell slots to outstations on a per-frame (period) basis;
wherein the basestation allocates upstream cell slots in upstream frame (period) n+1 to outstations by
a) inspecting upstream cell slot request slots in frame n;
b) arbitrating between contending cell requests using some allocation algorithm; and
c) informing outstations of their allocated cell slot(s) by broadcasting the information downstream before the start of upstream frame n+1.
Contending cell requests occur where the total of the requested cell capacity is greater than the capacity available to be allocated. Preferably the allocation algorithm is based on previous allocation history or on allocated priority.

If the frame size can be reduced down to a low value (without causing frame overhead to cause bandwidth inefficiency and at a minimum larger than (the maximum round-trip delay + time for all outstations to sequentially transmit cell requests + time for basestation to transmit cell allocations)), then this enables the opportunity for all outstations to have bandwidth allocated near instantaneously, i.e. within 1 frame of the request under low latency, and also allows the bandwidth request facility to have a resolution as low as a single ATM cell, as and when required.

In accordance with another aspect of the invention, there is provided a method of communicating information between a central station and a plurality of terminals in a distribution network, comprising the steps of: at the central station, determining downstream TDM frames, for transmission of distribution information and overhead information from the central station to the plurality of terminals, wherein is carried the allocation of ATM cell slots for the succeeding upstream TDMA frame, and upstream TDMA frames, for transmission of information in respective time slots from the terminals to the central station, wherein

upstream ATM cell slots are dynamically allocated, and wherein dedicated-per-user, short cell-request time slots in the TDMA frame are provided.

The above benefits in turn lead to a very low ATM cell latency and minimises the outstation buffer. An efficient use of upstream capacity is also enabled by tailoring capacity allocation to a value no greater than the capacity requirement. A further advantage is that instantaneous pre-emption of low priority traffic by high priority traffic is possible. This capability of allowing a dynamically varying upstream bandwidth to users can be extended from the requirement to send a single cell (e.g. for message acknowledgement) up to sustained use of the full channel capacity for high speed "data dumps".

Preferably, each slot request signal from an individual outstation simultaneously and independently supports cell slot requests for multiple queues. Each separate cell queue can be dedicated to cells of a given priority. The basestation can thus effectively allocate bandwidth on a traffic priority basis e.g. simultaneous use of the TDMA capacity is enabled for both higher priority Constant Bit rate (CBR) and potentially lower priority Variable Bit Rate (VBR) traffic.

Preferably, the slot request signal is quantised and companded. Each cell slot request signal from each outstation queue will thus be an approximate indication of the size of the appropriate queue. By quantising outstation cell queue size into a number of ranges where the number of ranges is smaller than maximum queue size (in terms of number of cells) or even the maximum upstream bandwidth capacity (in terms of number of cells per cell-allocation frame), and sending an indicator of the range the current queue size falls in, the length of the cell slot request signal can be minimised, which in turn leads to efficient use of upstream capacity.

In accordance with a still ffurther aspect of the invention , there is provided a TDM/TDMA communications network comprising a base station and at least one outstation, wherein each outstation has an ATM

cell slot request mechanism with an ATM cell slot request slot in every frame and wherein the basestation allocates ATM cell slots to outstations on a per-frame basis and this information is conveyed back to the outstations in the downstream signal, before the start of the next upstream burst.

Preferably, the each slot request signal simultaneously and independently supports multiple cell slot requests, each one pertaining to cell queues of differing priority. Preferably, the slot request signal is quantised and companded.

In accordance with a further aspect of the invention, there is provided an ATM based TDM/TDMA communications network comprising a base station and at least one outstation, wherein each outstation has an ATM, wherein each outstation has an ATM cell slot request mechanism involving a periodically assigned cell slot request slot and the basestation allocates cell slots to outstations on a per-frame basis; wherein the basestation allocates upstream cell slots in upstream frame n+1 to outstations by

a) inspecting upstream cell slot request slots in frame n;

b) arbitrating between contending cell requests using some allocation algorithm; and

c) informing outstations of their allocated cell slot by broadcasting the information downstream before the start of upstream frame n+1.

Given a cell queue size quantized into a limited number of ranges, companding of the size of ranges can allow both efficient usage of upstream capacity for a large number of low bandwidth users while also allowing varying proportions of total bandwidth (up to all of it) to be allocated on demand to "bursty" users. For example, the minimum cell slot request value could indicate that no cell is to be transmitted, next higher value could indicate a single cell to transmit and so-on with increasing steps up to a maximum request value which indicates when cell queue fill is greater or equal to maximum upstream capacity (per frame).

Brief Description of the Drawings

In order that a greater understanding of the invention be attained, reference shall now be made to the description and the figures as shown in the accompanying drawing sheets, wherein:

Figure 1 schematically illustrates a broadband service network;

Figure 2 illustrates the relation of the access node and Subscriber unit;

Figure 3 illustrates a TDM/TDMA frame structure for the upstream and downstream signals;

Figure 4 illustrates a frequency spectrum for downstream and upstream signals in a cable network;

Figure 5 illustrates ATM address segmentation;

Figure 6 illustrates data within cell request slots.

Figure 7 illustrates a cell allocation sequence;

Figure 8 illustrates a basestation cell slot allocation mechanism; and

Annex 1 provides a glossary of terms.

Detailed Description

Broadband networks need to support a mix of broadcast and interactive services, including data, in order grow in the future. Broadcast services include both analogue and digital formats, and interactive services include video on demand, Internet access, two way data, video telephony, voice telephony and telemetry for energy management and security. Figure 1 shows the main components of such a network.

The architecture described is suitable for deployment of interactive and broadcast services to suburban areas using a combination of hybrid fiber coax and remote digital electronics to provide the bandwidth, low latency, availability (i.e. small failure group sizes) and at competitive cost levels. Digital and analogue broadcast services are carried from a

headend in 6 MHz or 8 MHz channels to each home where channel selection is made at the set-top. These services are carried on 550 MHz or 750 MHz analogue fiber to a remote EO point (as indicated by BSR in Figure 1) which then serves several (80-240) home groups via coaxial cable. Digital video program channels are carried on 6 MHz or 8 MHz RF channels using 64 QAM modulation, which carries 3 to 9 program channels at 8 Mb/s to 3 Mb/s respectively per RF channel. Interactive services are connected to the distribution coaxial cable from a compact amplifier-sized device referred to in Figure 1 as an access node. This device performs the transition between optical signals on the fiber and electrical signals on the coaxial cable, summing the signals at the frequencies carrying interactive data with the signals at the frequencies carrying broadcast data, as will be discussed with reference to Figure 4.

The access network of a cable system is the equipment and infrastructures performing the transmission, multiplexing, concentration and broadcasting of service/application information flows between the end users of a given area and the rest of the delivery system (core network and servers), relevant control and management functions and transport of other services. The access node performs the adaptation between the Core Network and the access network. It processes the information flow such that they can be transported through the selected distribution networks. A fibre link provides bi-directional point to point digital transport between the CO and the access nodes (one fiber per direction). A Feeder Coax provides bi-directional point to multipoint transport for all services between the access node and the set top units. This is an analog transmission medium carrying digitally modulated signals. TDM/TDMA (Time Division Multiplexing / Time Division Multiple Access) transmission schemes are preferred in this shared coax medium, both for downstream/upstream resource sharing. TDMA is required in the upstream direction to account for different delays in transmission from set-top units which are physically located at various distances from the access node. The TDMA protocol manages the selection of timeslots and delay offsets for each set-top unit to ensure their upstream signals to the access node do not interfere with each other.

The access node communicates with the set top units situated in subscribers premises via the feeder coaxial cable which is essentially a common bus for all set-top units. Thus, in the downstream direction communications is point to multipoint, while in the upstream direction communications is multipoint to point. Each access node contains a basestation and each set-top unit contains an outstation. It is these basestations and outstations that manage the TDM/TDMA protocol. Each basestation connects to an access node modem, and each outstation connects to a subscriber set-top unit modem. An example of this is shown in Figure 2. The access node may be connected to more than one physical section of feeder cable ("coax leg") and so the implementation may choose to control each coax leg with a separate basestation or alternatively a number of coax legs may be common to a single basestation. Furthermore within any single coax leg there may be a single basestation controlling all outstations, or alternatively a number of different basestations may operate through broadband modems at different frequencies.

In this implementation a data rate of 20.48 Mbps can be employed in both the upstream and the down stream directions to accommodate broadband interactive services. The TDM/TDMA protocol makes use of 125 microsecond frames in both directions, although the structure of the frames is different in each direction. As only user traffic in ATM cells can be supported by this protocol, the protocol has been designed to maximize the number of ATM cells that can be supported in each direction. The particular frequencies, rates, frame lengths and frame formats used may be varied dependent on user requirements, data flow etc. Figure 3 shows a suitable TDM/TDMA structure for the upstream and downstream signals.

To support Multi Megabit Interactive (MMI) services on HFC, the allocation of various spectrum bands may vary in different countries. The following description expands on the North American spectrum allocation as an example to illustrate how frequencies can be allocated on the spectrum to satisfy the requirement of MMI.

Figure 4 shows the spectrum on the coax part of the HFC. Present and projected frequencies are shown. Downstream broadband traffic will exist between 470 and 530 MHz, while the upstream broadband will exist between 770 and 800 MHz. The use of the high end of spectrum for upstream data is preferred to provide greater capacity and improved noise margins with respect to the low end. It is also recognised that high burst data services such as "peer to peer data" and "at home www (world wide web) pages" may not be realizable if the low end is used for the upstream data transmission. Even some services, such as video telephony, which are technically feasible may not be viable economically. For example, the use of high end in this case results in a cost effective plant architecture. On the other hand, the low split design requires the plant to be split too many times. The spectrum for interactive services with large upstream bandwidth will utilise the spectrum otherwise used for minority interest group channels. Modems in the access node and the set-top unit use for example 15 MHz of bandwidth per direction (downstream and upstream) on the coax. The low split upstream (5-40 MHz) is not used, to ensure future interoperability with existing CATV upstream signals (PPV, remote monitoring, low bit rate data services). The low split bandwidth is passed by all elements of the broadband services network.

The broadband and telephony data streams can be transmitted on the forward and return paths using a Differentially encoded Quaternary Phase Shift Keyed (DQPSK) RF carrier (QAM or other modulation schemes may be used instead, based on channel characteristics). Access is via a Time Division Multiplex (TDM) in the forward path and Time Division Multiple Access (TDMA) on the return path. Duplex transmission is achieved by frequency division, with forward and return frequencies allocated as shown in Figure 4.

The access node uses one basestation module/broadband modem per coax span, to communicate with the set-top units. Each set-top unit also contains an outstation module/broadband modem which communicates to the access node The two modems (i.e. access node and set-top unit

modems) have a raw data rate of 20.48 Mbps (including all ATM and TDM/TDMA protocol overheads). Thus each access node modem requires 13.3 MHz (20.48 Mbps /1.5 bits/Hz) of spectrum. The access node and set-top unit modem have both been allocated 15 MHz of spectrum to allow a margin above the theoretical requirements.

The TDMA protocol used relies on the outstation upstream bursts arriving at the basestation in the expected time slot within a certain phase and receive power uncertainty. This is acheived using marshalling. There are two marshalling processes. Attachment marshalling and steady state marshalling: Attachment marshalling is used to: identify and "attach" each set-top unit on power up/connection, denying attachment to set-top units which are not recognized as valid. An attached set-top unit is allocated an upstream cell request channel and an short ID used for upstream cell slot allocation, and is considered active. Loop delay and received power from the set-top unit are measured in order to provision the set-top unit with the appropriate offset delay and launch power. Steady state marshalling is used to maintain an outstation from drifting outside the acceptable offset delay and launch power envelope and is a sub-set of attachment marshalling

The marshalling process can reliably be used on coax spans up to 2000 m long. Beyond 2000 m the delay differences can be too great to be handled by the TDM/TDMA protocol implemented. Increasing the maximum delay difference that the protocol can handle would decrease its efficiency in terms of ATM cell transport. The maximum round-trip delay inherent in the protocol is sufficient for the application targeted.

Once the upstream frame offset for an outstation is programmed, an outstation is provisioned to transmit within a unique sequence or sequences of symbols within the upstream frame. In order to achieve the DQPSK modem technology used for this system, between the last symbol of a data burst from one outstation and the first symbol of a data burst from the next outstation, there shall be a guard slot to prevent inter-burst interference. The first symbol of every data burst shall be a

reference symbol as the data is differentially modulated. All successive symbols in the data burst shall be independent of the physical layer.

Referring now to Figure 5, in order to simply route cells downstream through the Broadband Access Network, a hierarchical ATM addressing scheme is employed. To allow simple VP routing through the Broadband Services Network, all ATM signalling connections are condensed into a single VP, and routed in the Broadband Access Network on VCI information. Similarly a single VP may be used to support all high priority connections to all STUs on a given coax span; cells belonging to individual connections being selected by the correct STU outstation based on the VCI identity. Similarly again a single VP may be used to support all low priority connections to all STUs on a given coax span. Private VPs are routed to individual STUs; broadcast cells will be received by all STUs on the network.

A sequential description of the data path follows:

In the downstream direction: Within the access node the SONET interface is terminated and the cell stream is descrambled. A check for a valid HEC is carried out and invalid cells are discarded. Physical layer OAM cells and access node OAM cells are extracted within an NTC function, and the downstream cell stream is broadcast to all broad band basestations within the access node. Each broad band basestation latches and queues downstream cells from the cell stream received from the SONET interface in accordance with its provisioned ATM address filters.

Each downstream broad band basestation shall have a queue handling function, that shall cause outgoing cells to be accessed high priority first on a First-In First-Out (FIFO) basis. Where no high priority cells are queued, low priority cells shall be accessed on a FIFO basis. Where no low or high priority cells are queued, the queue handling function shall generate an idle cell. Cells are then transmitted continuously to a broadband modem in accordance with downstream frame format as

shown in Figure 6. The broadband modem shall modulate the signal and transmit to the coax.

The downstream signal is demodulated by all STU modem receivers tuned to the particular broadband modem frequency and each cell with an appropriate address is latched by the outstation and passed to the set-top box unit for processing.

In the Upstream direction: The STU internal interface to the Broadband Outstation Module operates as two Queues, into which the STU writes 53 byte cells. Each Broadband Outstation Module maintains two Queues: High and Low delay priority.

Each Broadband Outstation Module has a queue handling function, that causes outgoing cells to be accessed in a similar fashion to the base station. The Broadband Outstation Module prevents egress of cells onto coax with VPI/VCIs not in its VPI/VCI table. Upstream cells have a single byte BIP check calculated and appended to each cell (to allow upstream performance monitoring). The outstation transmits cells in TDMA slots in accordance with upstream format as shown in Figure 7 only when authorised to do so. The outstation module shall pass the signal burst to the modem which modulates the burst and transmits it to the coax.

At the basestation the upstream signal is demodulated and the cells are queued in the access node. Each broad band basestation has a single queue with no indication of cell delay priority. Cells with an invalid HEC are discarded. Idle cells or empty cell slots are detected and discarded. The upstream cell flow control method results in cells queuing back at the outstation/STU when the aggregate required bandwidth over either the coax or fibre is greater than the actual bandwidth. The broad band basestation uses the fill level of its queue to regulate the cell allocation algorithm, so that it cannot ever overflow. The broad band basestation controls the flow back to the Broadband Outstation Modules, which can be achieved by ceasing/reducing cell allocation. The short term buffer

size within the broad band basestation can reflect the latency of the flow control mechanism.

Cells from the broad band basestation queues are passed via an NTC function, where they are combined with physical layer OAM and injected OAM cells from the access node management functions, and assembled into an STS frame for transmission over a SONET link to the ATM switch.

Referring again to the coax TDM/TDMA frame structures shown in Figure 3, 125 µsec frames at 20.48 Mbps are shown, which can provide 320 bytes (20.48 Mbps/8bits/byte*125 µsec = 320 bytes). In the downstream direction: 5 bytes are used for the CSF (Control Sub Frame) which allows for housekeeping, ranging and tracking control; 5 bytes are used for the upstream CAF (Cell Allocation Field) which is used to inform outstations which upstream ATM cell slots to use in the following upstream frame; 1 byte is used for the BIP (Bit Interleave Parity) which is used for error detection; and 309 bytes are used for the ATM payload, which allows for 5 whole cells and 44 bytes of an additional cell. Thus ATM cells can be split across two consecutive frames. The outstation is able to reconstruct the ATM cells transmitted in this fashion. This enables very high bandwidth efficiency in the downstream direction (i.e. 309 of 320 bytes are used to transmit ATM cells - 96.6% bandwidth efficiency). The access node basestation simply broadcasts all received cells to all set-top units, whilst each set-top unit processes only those cells addressed to it.

In the upstream direction, the frame is divided as follows:

55 bytes are used for cell slot E which is used for ATM payload as well as for other housekeeping purposes (marshalling, cell request channels);

45 bytes are used as cell request channels. Each cell request channel is 10 bits wide, allowing for 36 cell request channels per frame. These request channels are used by the set-top units to request upstream ATM bandwidth (i.e. ATM cell slots);

the remaining 220 bytes are used as 4 further ATM cell slots, each 55 bytes wide. Thus, each cell slot contains a 53 byte ATM cell as well as 1 byte of guard slot (required by the TDMA protocol), and 1 byte for BIP (for error detection).

This upstream traffic bandwidth is therefore 4 cell slots (A,B,C & D) every frame plus shared use of an additional cell slot (E).

Cell slot E can be used in two modes:

1. To support up to 72 set-top units on coax spans up to 2000 m long, cell slot E will be used for ATM traffic or marshalling or control/status responses; and

2. To support up to 127 set-top units on coax spans up to 500 m, cell slot E will be used for cell request channels and marshalling or control/status responses (i.e. cell slot E can not be used for ATM traffic in this latter mode).

Since all these functions within cell slot E (marshalling, control/status responses or ATM traffic) are mutually incompatible on a simultaneous basis, the use to which this slot is put must be different for different frames. On command from the processor for a marshalling or outstation register access (which are mutually exclusive by means of the protocols used), the hardware will inhibit use of cell slot E for ATM cells by writing 0 to Cell E allocation byte in the downstream frame immediately preceding the upstream frame during which a response will occur. At all other times, this cell slot will be available for the cell allocation algorithm to use as necessary. This dynamic use of the upstream frame for marshalling/housekeeping/traffic, allows the bandwidth available for traffic to be maximised.

In the upstream direction a mechanism is required to allow outstations to request upstream bandwidth and then transmit in the cell slots allocated to them. This process requires a fair allocation of bandwidth across all outstations attached to a basestation. Each outstation is allocated one 10 bit cell request channel every other frame upon marshalling. Thus there can be up to 72 active set-top units per access node basestation (36 cell request channels per frame x 2 frames) without using cell slot E

for request channels. As cell requests are received over 2 frames, upstream allocations are also handled on a 2 frame basis in this implementation. The bandwidth assignment mechanism is as follows: The upstream cell request channel will be at a default point within the upstream frame e.g. outstations with SIDs 0 to 63 have cell request channels in odd frames, outstations with SIDs 64 to 127 have cell request channels in even frames. Outstations with SIDs 63 or 127 have cell request channels immediately prior to Cell A etc., as shown in Figure 7.

The 10 bit cell request channel has 4 usable bits, with the remaining 6 bits for use as a guard slot and reference symbol (as required by the modem technology). When an outstation wishes to transmit upstream, it uses its cell request channel to indicate how many cells are in each of its queues (each outstation has a low priority and a high priority ATM queue for upstream transmission). With 2 bits per queue, each queue request can have 4 states (these states are used to indicate queue fill e.g. 0 cells, 1 cell, 2-3 cells, 4 or more cells for the high priority queue / 9 or more cells for the low priority queue). The meaning of the cell request will depend on the priority.

Once the basestation has received all requests over 2 frames it will allocate upstream cell slots. Once the allocation decision is made, the basestation indicates allocations to the outstations by placing the outstation's short identity (ID) in the downstream CAF corresponding to the upstream cell slot(s) that the outstation has been allocated. It is at this point that the Basestation can pre-empt the cell allocation mechanism and inhibit use of the default marshalling window / ATM cell slot for use by ATM traffic so that its use is available for an upstream marshalling response. The basestation does not keep track of requests from one allocation cycle to the next. It is up to the outstations to keep requesting cell slots until they are able to transmit the ATM cells in their queues. To prevent downstream errors causing upstream contention and hence loss of cells from two (or more) outstation modules, each downstream allocation byte contains a parity check mechanism. Where

a cell slot(s) is unavailable/unused, its allocation byte shall be a null SID (0).

The algorithm assumes that the cell allocation (which does not carry a priority allocation field) would go to high priority queues first. i.e. even if a cell slot was allocated in response to a low priority cell request, that assigned cell slot may be subsequently used (by the outstation) for a high priority cell being queued after the initial cell request had been sent.

In one embodiment, the Basestation shall accept cell requests from all outstations i.e. 2 frames worth, before allocation commences. Allocation will consequently extend over 2 frames also. The principle behind cell request / cell allocation is that outstations keep asking for the cell slots they need until they have been granted. This prevents the Basestation from needing to keep "historical" records of cell request. Cell allocation is received within a frame of an upstream cell request, the Broadband Outstation Module outputs the subsequent frame cell request before sending the cell. In order to simplify the cell allocation algorithm at the basestation, the Broadband Outstation Module shall take account of current cell allocation in transmission of the succeeding cell request. i.e. if a cell slot is requested and granted in 1 frame, then the next cell request will be zero (assuming no further cells have been queued) although that first cell is still queued in the outstation module.

The cell allocation sequence is as follows: the delay from the transmission of the start of the downstream frame to the receiving of the start of the upstream frame at the basestation is the same for all outstation modules and shall be nominally 1/2 frame (>20μs and <83μs). This allows a common frame interrupt to the access node's sub-system microcontroller. The broad band basestation shall use the cell request to generate cell allocation bytes. The actual value granted will depend on a number of factors, but given a quiescent system, cell allocation will be equivalent to the fill (lower limit). e.g. if a low priority request is received = "10", then up to 3 cells will be granted. This will limit the maximum upstream capacity of high priority connections to 4 cells per 250μs. This is approximately equivalent to an ATM payload of 6Mbit/s.

The maximum upstream capacity of low priority connections will be 9 cells per 250µs. This is approximately equivalent to an ATM payload of 13.5Mbit/s. Although suffering from increased cell delay variation, this rate will allow LAN emulation across the BB access network. The basestation shall use the received quality level of the incoming signal to determine the validity of a cell request. Cell requests received in a channel where the quality is less than a pre-determined value shall not results in cell allocation. Empty Cell Request slots shall be interpreted as no cell request.

The following is a description of the cell allocation method implemented as an example. For each priority, each cell request message is inspected upon arrival and the requested capacity in cell request channel #n is allocated to outstation # n. To ensure a "fair" allocation mechanism, for each priority supported, a FIFO is available as allocation memory, equal in size to maximum number of upstream slots; and hardware shall maintain from one allocation session until the next, the ID of the outstation to which it allocated the last cellslot. This ID is referred to as the start pointer. Once allocation memory is at full upstream capacity, the oldest requests are overwritten until ID# of originator of oldest request equals to the "start pointer". Once all cell requests have been received, the upstream capacity is allocated to the limit of calculated capacity, starting with the high priority earliest data. If all high priority requests cannot be allocated, the "start pointer".(high priority) is set to the last allocated outstation ID and allocation stops. Otherwise, the "start pointer".(high priority) is set to 0, and continues allocating low priority / earliest data. If all low priority requests cannot be allocated, the "start pointer".(low priority) is set to the last allocated outstation ID. or otherwise the "start pointer" .(low priority) is set to 0. This mechanism allows that if all requested cell slots were not granted in a certain allocation frame, then the outstations that missed out receive priority next time.

Figure 8 show a simple implementation mechanism, with a capability of allocating 4 Cell slots. For the cell allocation algorithm described above and in Figure 6 , since up to 5 cells are allocated per frame and

algorithm operates over 2 frames, then the ID store would need to be 10 SIDs deep.

CLAIMS:

1. A TDM/TDMA protocol operable in a communications network wherein each outstation has an ATM cell slot request mechanism with an ATM cell slot request slot in every frame and wherein the basestation allocates ATM cell slots to outstations on a per-frame basis and this information is conveyed back to the outstations in the downstream signal, before the start of the next upstream burst.

2. A TDMA protocol according to claim 1 wherein each slot request signal simultaneously and independently supports multiple cell slot requests, each one pertaining to cell queues of differing priority.

3. A TDMA protocol according to claim 1 wherein the slot request signal is quantised and companded.

4. A method of communicating information between a central station and a plurality of terminals in a distribution network, comprising the steps of: at the central station, determining downstream TDM frames, for transmission of distribution information and overhead information from the central station to the plurality of terminals, wherein is carried the allocation of ATM cell slots for the succeeding upstream TDMA frame, and upstream TDMA frames, for transmission of information in respective time slots from the terminals to the central station, wherein upstream ATM cell slots are dynamically allocated, and wherein dedicated-per-user, short cell-request time slots in the TDMA frame are provided.

5. A method according to claim 4, wherein each slot request signal simultaneously and independently supports multiple cell slot requests, each one pertaining to cell queues of differing priority.

6. A method according to claim 4, wherein the slot request signal is quantised and companded.

7. A TDM/TDMA protocol operable in an ATM based communications network wherein each outstation has an ATM cell slot request mechanism involving a periodically assigned cell slot request slot and the basestation allocates cell slots to outstations on a per-frame basis;
wherein the basestation allocates upstream cell slots in upstream frame n+1 to outstations by
a) inspecting upstream cell slot request slots in frame n;
b) arbitrating between contending cell requests using some allocation algorithm; and
c) informing outstations of their allocated cell slot by broadcasting the information downstream before the start of upstream frame n+1.

8. A method according to claim 7 wherein there is an assigned slot request in every frame or in every period comprising a number of frames.

9. A method according to claim 7 wherein the slot request signal is quantised and companded.

10. A TDM/TDMA communications network comprising a base station and at least one outstation, wherein each outstation has an ATM cell slot request mechanism with an ATM cell slot request slot in every frame and wherein the basestation allocates ATM cell slots to outstations on a per-frame basis and this information is conveyed back to the outstations in the downstream signal, before the start of the next upstream burst.

11. A network according to claim 10 wherein each slot request signal simultaneously and independently supports multiple cell slot requests, each one pertaining to cell queues of differing priority.

12. A network according to claim 10 wherein the slot request signal is quantised and companded.

13. A TDM/TDMA communications network comprising a base station and at least one outstation wherein information is passed between a central station and a plurality of terminals in a distribution network, in accordance with a method comprising the steps of: at the central station, determining downstream TDM frames, for transmission of distribution information and overhead information from the central station to the plurality of terminals, wherein is carried the allocation of ATM cell slots for the succeeding upstream TDMA frame, and upstream TDMA frames, for transmission of information in respective time slots from the terminals to the central station, wherein upstream ATM cell slots are dynamically allocated, and wherein dedicated-per-user, short cell-request time slots in the TDMA frame are provided.

14. A TDM/TDMA communications network according to claim 13, wherein each slot request signal simultaneously and independently supports multiple cell slot requests, each one pertaining to cell queues of differing priority.

15. A method according to claim 13, wherein the slot request signal is quantised and companded.

16. An ATM based TDM/TDMA communications network comprising a base station and at least one outstation, wherein each outstation has an ATM, wherein each outstation has an ATM cell slot request mechanism involving a periodically assigned cell slot request slot and the basestation allocates cell slots to outstations on a per-frame basis;

wherein the basestation allocates upstream cell slots in upstream frame n+1 to outstations by

a) inspecting upstream cell slot request slots in frame n;

b) arbitrating between contending cell requests using some allocation algorithm; and

c) informing outstations of their allocated cell slot by broadcasting the information downstream before the start of upstream frame n+1.

17. A method according to claim 16 wherein there is an assigned slot request in every frame or in every period comprising a number of frames.

18. A method according to claim 16 wherein the slot request signal is quantised and companded.

The Patent Office

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4P (PPK & PPG); H4K (KTK & KOT) and H4M (MN, & MTQX1-3)

Int Cl (Ed.6): H04L (12/403, 12/423 & 12/18); H04Q (11/04) and H04J (3/16 & 3/24)

Other: None

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2289812 A	NORTHERN TELECOM	None
A	US 5594738	MOTOROLA	None
A	US 5297144	SPECTRIX	None

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